EXPERIENCE IN RECOVERY OF CHILLED BLAST FURNACES[1]

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Abstract

Over the last seventeen years, thirty–three chilled blast furnaces have been recovered with assistance of Danieli Corus. Of the approximately 600 blast furnaces around the world, per year around five suffer from a chilled hearth. One can imagine that the global recovery experience is limited. However, due to the frequent involvement of Danieli Corus in complex blast furnace process circumstances, recovery expertise is developed continuously. Blast Furnace chills can be classified from minor (connection lost, but sufficient heat in the hearth) to very severe chill (connection los and all liquids in hearth are frozen). Classical recovery methods applied up to moderate chills may be successful in the end, but if not, the starting point for recovery is worsened and this may lead to a severe chill. For furnaces experiencing severe chills, Danieli Corus have developed a special “oxy fuel lance technology”, because classical recovery methods take too long time. Even with moderate chills, the use of oxyfuel lance technology can speed up the recovery process.The measures differ depending on the extent of the chill, and so, early notification is always recommended for the quickest recovery. All recoveries in which Danieli Corus participated, but one, were successful and brought the blast furnaces back to full production within 200 hours.

Key words: Blast furnace; Recovery; Chil; Chilled hearth; Lancing; Oxy–fuel technology.

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INTRODUCTION

A chilled blast furnace is one of the most serious disruptions in an integrated steel plant, as it might take weeks to bring the furnace back to normal production. During a hearth chill, liquids cannot be tapped since the temperature in the lower part of the furnace has become too low. The connection between the taphole and tuyeres has been lost, primarily owing to solidification of slag. This solidified slag obstructs the flow of liquids into the hearth. If a chill is very severe, the remaining hot metal in the hearth may start solidifying as well.

Blast Furnace chills can be minor (connection lost, but sufficient heat in the hearth) to very severe (connection lost and all hearth contents solidified). Classical recovery methods may be successful with moderate chills, but if not, the starting point for a following recovery attempt is worsened and this may lead to a severe chill.

Danieli Corus has developed “oxy–fuel lance technology” for severe chills, which take too much time to recover from when using traditional methods. On top of that, the use of these oxy–fuel lances will speed up recovery from moderate chills considerably.

Figure 1 Severe chill: very little heat in the hearth (4.5 meter core drill through taphole)

Over the last seventeen years, thirty–three chilled blast furnaces have been recovered with assistance of Danieli Corus. All recoveries in which Danieli Corus participated, but one, were successful and brought the blast furnaces back to full production within 200 hours. The rare occurrence of chilled hearths (averaging at around five instances per annum) makes Danieli Corus’ expertise in bringing furnaces back to normal under these complex process circumstances unique and very valuable.

BACKGROUND

Solidification of slag can already start at temperatures as high 1350 – 1390 °C, depending on the slag composition (ratio of CaO + MgO, SiO_2, and Al_2O_3). In addition, FeO (unreduced iron oxide) plays an important role. The slag becomes viscous and difficult to drain from the furnace. During a hearth chill, the slag composition will usually change resulting in changes of viscosity and melting temperature. The latter is always higher than the melting temperature of iron.

During a hearth chill it is much more difficult, but also much more important, to drain the slag from the furnace, than to drain the iron.

Causes for the chill can be various:

- Excessive water leakage
- Process related problems, such as:
    - Raw materials out of specification or having very irregular properties over time.
    - Malfunctioning of instruments or measuring devices.
    - Incorrect understanding of the blast furnace process by the operators or technologists. Front–line operators acting too late or not at all on developing process problems. Early warning signs are not timely reported to management.
    - Inadequate operational practices (e.g. water search discipline, casthouse work, plugging tuyeres).
    - Insufficient experience with abnormal process situations.
- Unprepared emergency stops due to:
    - Sudden breakdown or failure of key components of the furnace, such as Charging system, Hot blast system (incl. tuyeres) or the Gas collecting system, requiring major repair
    - Hearth or taphole breakout requiring a stop of several days (weeks) to repair.

Except for an emergency stop, the normal practice of blast furnace operators to a “near chill situation” is to continue operations at reduced wind–volume while trying to improve the excavation of liquids by drilling and/or oxygen lancing. If draining is not successful, hot metal and slag continue to accumulate in the hearth. Very likely, the furnace will have already suffered from hanging and slipping by this time. Additional fuel can be charged but the process is by now seriously deteriorated. If the connection is not improved, the furnace has to be stopped due to safety reasons. If the decision to stop the furnace is postponed too long, high liquid levels may lead to burning tuyeres, coolers and blowpipes. The furnace will eventually stop, but this situation is very unsafe.

The situation can usually be characterized as follows:

- It is impossible to open the taphole by lancing or drilling.
- Tuyeres and blowpipes are filled with slag.
- Some tuyeres even have solidified material in front of them (from melting zone or unreduced iron)
- The layer structure in the stack has been disturbed by frequent slips.
- Slag/melt has accumulated to halfway the bosh or even higher.
- Furnace coke rate of 300 – 700 kg/tHM, depending on fuel injection and remedial actions already taken for the process upset.
- Due to the process upset, it is very likely that additional water leakages occur.

Figure 2 Slag–filled tuyere

Today's operating practice with high coal injection levels (200 kg/tHM and higher) makes it even more difficult to restart operation after more than a few days of unprepared stop. The main reasons are that the burden at tuyere level has a major fuel deficiency and that PCI cannot be started below a certain blast volume.

It is evident that symptoms of chilling should be recognized in an early stage and that remedial actions for recovery are taken as soon as possible. This would make starting conditions for a successful recovery most favorable. In such hectic circumstances, it is recommended to consult experts in recoveries as soon as possible.

In extreme cases, it will be very difficult to recover the furnace by melting. If the recovery fails in this situation, the furnace will have to be raked out; this can take eight to twelve weeks. This consequence will be more likely if:

- The furnace contains excessive amounts of solidified slag
- There is a lot of water ingress
- Very little coke remains in the deadman

RECOVERY

For a good recovery plan, the status of the furnace at the start of the recovery is very important.

The process status should be asserted based on the following steps:

1. Estimate the burden composition (and coke rate) in the furnace,
2. Estimate the slag and hot metal levels,
3. Determine the chemical composition of the burden and the slag just before the chill,
4. Verify whether all water leakage into the furnace has stopped,
5. Identify over which taphole the recovery will start,
6. Determine the coke rate and basicity of burden to be charged,
7. Clean tuyeres/blowpipes and plug them (except the ones to start the recovery with),
8. Determine number of open tuyeres for the start of the recovery.

If the hearth has been drained empty, such as is the case after a hearth breakout, the recovery is more straightforward then when the furnace is full of slag and water or both. Furnaces with process related problems are generally more difficult to recover.

The following actions have to take place to recover the furnace:

- Re–establish the connection between tuyeres and tapholes
- Bring maximum heat into the furnace, for re–melting liquids

- Re–melt the slag and make it as liquid as possible
- Drain liquids from the furnace,
- Normalize the process.

The above steps can be realized in different ways and with every step of the recovery plan, the current situation has to be clear before deciding on the next step. As to the timing and magnitude of certain actions, it is very difficult for such judgment calls to be made when little or no experience of chilled hearth recoveries is available, and this in itself can lengthen the recovery process.

THE RECOVERY PROCESS

The tuyere–taphole connection might be re–established by hand lancing or burning with thermal lances. This involves very hard with many hazards in a very hot working environment. The amount of heat that can be introduced with this method is very limited and barely enough to re–melt slag in a narrow passage from tuyere to the taphole. As long as no wind is on the furnace, the heat loss will excess the heat generation, so the furnace will continue to cool down. And putting the furnace back on wind before establishing a connection through which the liquids that will then be produced can be drained, the liquids will accumulate and damage blowpipes and coolers. Danieli Corus relies on oxy–fuel lance technology for swifter recovery. The lance technology is complemented by pivotal operational experience, a proven combination.

Danieli Corus' approach for chilled furnace recoveries is straight forward:

- Try to re–establish the tuyere–taphole connection as soon as possible using traditional methods
- If this is not accomplished within an acceptable time frame or simply impossible, use Danieli Corus oxy–fuel lances

Additional measures for safe and fast recovery are related to burdening and slag composition, plugging method and opening sequence of tuyeres, use of available instrumentation to monitor the progress of the recovery, PCI and so on. Danieli Corus have performed many recoveries and clearly, every hearth chill has individual characteristics, in terms of cause(s) and condition of the furnace. Through this experience, Danieli Corus are in the unique position to improve the recovery process continuously, leading to reduced down time of the furnace in question.

Danieli Corus can send a site team consisting of operators, technologists and engineers, all highly skilled and experienced with respect to recoveries, within twenty–four to forty–eight hours. The oxy–fuel lances and control stations are always "ready to go" and the equipment can be shipped to the client's site as soon as possible so it's in place when required.

Figure 3 Oxy–fuel recovery equipment "ready to go"

Quick response is crucial for recovery. In the early stages of the recovery process, checklists, operational procedures and a rudimentary recovery plan will be communicated and drafted with the client.

If the traditional recovery remains unsuccessful, the oxy–fuel equipment will be used upon arrival. Then, Danieli Corus sends a team of additional specialists to install and operate the oxy–fuel equipment. This team has specialists with respect to drilling the furnace for lance operation and subsequent operational expertise. The lances will be operated in shifts by Danieli Corus personnel under supervision of the client.

Figure 4 Drilling of hole for oxy–fuel lance

Figure 5 Damaged core drill: substantial amounts of solidified iron in hearth

Figure 6 Core taken out of drilled hole; presence of coke will contribute to the recovery

Holes for insertion of the oxy–fuel lances are drilled in the furnace, usually done through the taphole(s). Concurrently, the oxy–fuel equipment is inspected and assembled. Before the actual start of the recovery operation, the oxy–fuel lances are test fired in the casthouse at maximum flow rates.

Figure 7 Test firing of oxy–fuel lance

It is important that during the recovery, tuyeres do not open spontaneously. This would re–start production of liquids at these tuyeres, leading to burning of blowpipes or jumbo coolers and thus resulting in unnecessary delays during the first critical days of the recovery. To prevent spontaneous opening of tuyeres, special ceramic plugs are installed. The design is such that these plugs can be easily broken by the time it is safe to open up additional tuyeres. Special thermocouples are installed in front of the tuyere noses to monitor whether a tuyere is ready for opening up.

Figure 8 Plugged tuyere

After insertion of the lances, they will ignite at relatively low volumes of gas and oxygen; this is the start of the blow–in phase. The lances will be in operation at full power for twenty–four hours or more. The lance operation results in a hot gas flow through cracks in the solidified material and voids in the burden from the tapholes upwards (see Figure 11), heating up and re–melting solidified material to re–establish a good, consistent connection to the tuyeres. The ratio between gas and oxygen is critical; excess oxygen will burn back the lance and excess gas leads to further chilling of the furnace, either through transfer of heat from the hearth contents onto the excess gas or through the endothermic reaction in which natural gas is split into carbon monoxide and hydrogen in the presence of iron (Fischer Tropsch process). The optimal ratio always depends on internal conditions of the furnace, so experience is essential.

Temperature spikes detected by the thermocouples installed in the tuyeres indicate that the connection between the lance tip and the tuyere nose is established. This is a precondition for the next step in the recovery process: to open a few tuyeres carefully and to put wind on the furnace, whilst still operating the lances at full power.

Figure 9 Opening a tuyere

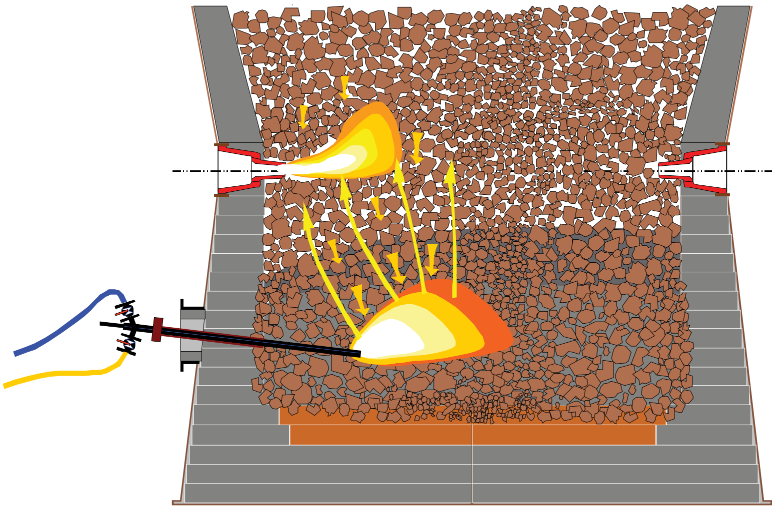

Figure 10 Heating up with oxy–fuel lances and a few tuyeres

The opening of a few tuyeres will lead to increased liquid production, which can be monitored by the embedded thermocouples on the lances. At a certain moment, the amount of liquids produced requires the furnace to be tapped.

Tapping is done by cutting the lance after it has been isolated from the gas and oxygen circuits. Casting will usually follow immediately and significant amounts of slag and metal will be cast at high temperatures. Plugging the taphole requires special precautions as the diameter of the hole is larger than normal, and the position is sometimes at a different.

Figure 11 Cutting an oxy–fuel lance

The lance(s) that are still operating at other positions will be kept in operation as long as possible under predefined conditions determining flame temperature, amount of heat introduced in the hearth, the composition of the reduction gas and the lance burn–back rate. When fresh coke from the coke blank has reached the open tuyeres, adjacent tuyeres can be opened, but this has to be done carefully. Gap–times between casts will decrease as more tuyeres are opened.

After some time, depending on the process conditions and the thermocouple readings, the remaining lances are stopped and removed too. By that time, the furnace hearth should be sufficiently hot, and the remaining tuyeres can be opened gradually and in a controlled manner. The tuyeres should be duly plugged, to avoid spontaneous opening. However if this happens, they should be plugged as soon as possible since it is very likely that isolated tuyeres produce pools of liquid slag and iron that cannot be drained. This may lead to burning of cooling elements. If 50% of the tuyeres are open, the furnace can be considered recovered.

CONDITIONS FOR A SUCCESSFUL RECOVERY

A large number of blast furnaces have been recovered using the oxy–fuel lance technology under various circumstances. The state of the process prior to the chill will influence the time required for the recovery but will not be the only parameter critical for success.

The following conditions should be met:

- There should be enough coke in the centre of the hearth (the deadman) and the drilled holes should indicate natural draught throughout the deadman.
- The furnace must be free of water leakage before recovery is attempted. Any water entering the furnace during the initial stage will compromise the recovery and might eventually be ‘killing’
- The recovery must be performed in the correct way from the start on to be successful. Restarts seriously extend and complicate the recovery process.

MANAGING A RECOVERY

A chilled hearth puts blast furnace operation as far out of the ordinary as one can imagine. But even though the length and especially the progress of the recovery are unpredictable, the situation should be managed just as if it were a controlled special situation in day to day blast furnace operation (compare to e.g. blow–in after maintenance stop).

Recovery will only be successful with a joint effort from local teams co–operating with external colleagues. Total commitment to both the situation and each other is essential. Manpower planning should be made clear and synchronized.

Blast furnace operational personnel will normally work in shifts (like 2x12 hours). This holds for blast furnace management, casthouse operators, etc. Shift changes will have to be scheduled twice daily. Especially during extensive recoveries, key personnel tend to get both physically and mentally exhausted. Scheduling one or two days off for these people will help them recover and in the end contribute to the chill recovery.

Regular recovery management meetings are required. A suggested agenda is given in the table below.

Recovery Progress Meeting
Safety Issues
Follow–up List
Review last 12 hours
Plan for next 12 hours • Casthouse • Tuyere Floor • Process/burdening, furnace internal state
Mainentance Issues
Other

Another important issue for recoveries is that every step in the recovery process may cause incidents or problems. Potential consequences are that the furnace chills again or that it becomes clear that the chosen method does not work. Therefore, even though the recovery plan has to be followed, a contingency plan should always be in place. E.g. if the plan envisages hand lancing the connection between tuyeres and taphole, the contingency could be to use Danieli Corus oxy–fuel lances. An ultimate contingency could be that if the recovery efforts are unsuccessful, the furnace will have to be emptied by digging out (6–10 weeks).

Figure 12 Discussion of furnace internal state during progress meeting

EXPERIENCES

During the many successful recoveries executed by Danieli Corus in recent years, recovery teams encountered widely differing circumstances like causes for the chill, process status, etc. We will discuss a few of these situations. Figure 14 shows the time line of several recoveries.

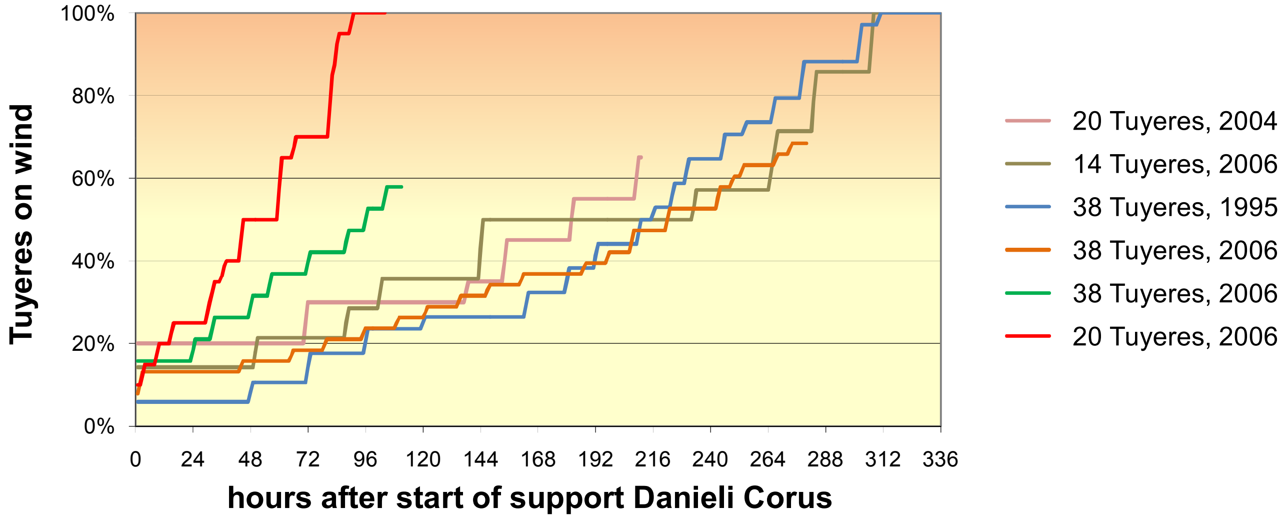

Figure 13 Timeline recoveries

Example

- Working Volume 2780 m³
- 3 tapholes: North, East, South
- 29 tuyeres
- Distance taphole– tuyeres 3.5 m
- Taphole angle 10 degrees

The furnace was stopped within a week after the regular blow–in because of a failure in the hot blast system. Traditional recovery was difficult, and resulted in a burnt blowpipe. This finally resulted in a serious chill with all blowpipes filled with slag. These events occurred shortly after a full reline during which a new hearth had been installed. The hearth had not yet been fully heated up which also promoted fast chilling conditions. The furnace was still on 100% coke operation when the chill occurred.

RECOVERY

Two holes were drilled into the hearth to a depth of 4.5 meters. One hole appeared to be a “blind” hole (fully immersed in solidified slag and not showing any draught). The other was drilled at a slightly higher elevation and into another taphole. An oxy–fuel lance inserted there was successfully ignited, and it burned for twenty–one hours; the oxy–fuel lance in the first blind hole could not sustain combustion.

Four tuyeres were initially opened, and six hours after opening the tuyeres, the first cast was made. Additional tuyeres were opened at ten to twelve hour intervals. The furnace was finally recovered in just under 200 hours and regained full production shortly afterwards.

CONCLUSIONS

Given the seriousness of a chilled hearth and the potential consequences of improper responsive measures, it is essential for a blast furnace operational department to have standard operating procedures for recognizing and responding to an out of control furnace in place. If a chill does occur, quick response is mandatory, but the complex process circumstances introduce additional risks.

Danieli Corus has an unrivaled track record in the recovery of chilled blast furnaces. And not only does the oxy–fuel technology make recovery most likely, it also offers major benefits in terms of speeding up the recovery process. The unique amount of expertise, accumulated during thirty–three recoveries is pivotal.

This combination of technology and operational experience has proven successful with a wide range of causes for the chill and always within the estimated time.